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A SURVEY OF CONDITIONS AFFECTING FISHERIES IN THE UPPER MISSISSIPPI RIVER¹

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GENERAL CONSIDERATIONS

INTRODUCTION

The ever-increasing needs of our complex civilization are constantly making new and larger demands on our natural resources, and the Mississippi River particularly is subject to these demands. Because of its physical characteristics the entire river in any given locality is rather easily accessible to man, and as this river is hundreds of miles in length it provides almost unlimited contacts with the various activities of civilization which so closely bound the river and by which the river is so easily modified. Besides, on few rivers have so many classes of people such varied claims as on the Mississippi, and in this connection it must be remembered that the river is a dynamic thing which often projects onto the affairs of individuals or communities at a considerable distance the effects of activities which would otherwise be purely of local interest.

The fisheries of the Mississippi River have long been recognized as national assets. La Salle and Tonti during the course of their early explorations on this stream remarked upon the large numbers of "huge catt-fish" which they saw in this river, and several early

¹The present Fishery Circular embodies the main items of the preliminary report of this survey as submitted to the Engineer Corps by the Bureau of Fisheries on November 10, 1930. A detailed report dealing with scientific data in full is to be published later by the bureau. Approved for publication, May 28, 1931.

writers mention the abundance of both fish and fresh-water mussels in the Mississippi. In the steamboating days fishing along the Mississippi was regularly good, if the numerous references to this sport found in the various books of and about that time be credited.

Following the discovery by John Boepple in the early nineties that the fresh-water mussels were of commercial value in the manufacture of buttons, and with the development in the last three decades of definite eastern markets for the rough fish of the Mississippi, the fisheries of the Mississippi expanded materially and include now not only game and sport fishing but mussel and commercial fisheries as well.

The U. S. Bureau of Fisheries has been concerned with all three of these activities through the propagation of bass and other game fish, through the fish-rescue work which has returned enormous numbers of young fish of all kinds to the Mississippi from the sloughs and backwaters in which small fish are so frequently stranded during the late summer, and through the propagation of fresh-water mussels. Besides, when Congress, realizing the great recreational value of certain portions of the Mississippi River between Rock Island, Ill., and Minneapolis, Minn., created the Upper Mississippi Wild Life and Fish Refuge as a sanctuary for game and fish, the U. S. Bureau of Fisheries became definitely affiliated with that project.

In the spring of 1930, after a canalization program for the upper Mississippi had been authorized by Congress in the interests of navigation, a conference attended by the Engineer Corps officers in charge of the districts of the Mississippi concerned in this program and by representatives of the U. S. Biological Survey and the U. S. Bureau of Fisheries, was held in St. Louis. It seemed desirable to those present at this meeting that a survey of the existing conditions as regards fisheries in the upper Mississippi be made with special reference to the dams now operating and the possible effects of the proposed construction incident to the canalization program. This survey was subsequently authorized and supported jointly by the Engineer Corps and the Bureau of Fisheries.

EQUIPMENT AND PERSONNEL

The Engineer Corps quarterboat *No. 348* was placed at the disposal of the U. S. Bureau of Fisheries, for the survey work. This boat provided ample living quarters for 12 people, as well as laboratory and working spaces, and as finally equipped carried a chemical laboratory adequate for all necessary chemical operations, two units for microscopic work, and a very complete series of collecting, sounding, and recording apparatus. In addition a 35-foot cabin cruiser and a catamaran, on which a mussel dredge was mounted, were towed as auxiliary equipment.

The personnel consisted of 6 aquatic biologists, 2 chemists, 1 cook, 1 helper, and 1 boatman.

The material collected was forwarded to the U. S. Bureau of Fisheries field station at the University of Missouri, Columbia, Mo., where the bacteriological work and the analyses and identifications were completed by the staff of the Fisheries unit.

EXTENT OF SURVEY

The survey as originally planned was to determine as far as possible the physical, chemical, and biological conditions bearing on fisheries problems now existing in the Lake Keokuk district. From the data gathered there it was hoped that statements could be made concerning the probable sequence of changes to be expected in those portions of the Mississippi River in which dams are to be erected in connection with the 9-foot channel.

In August, 1930, after the first part of the survey was almost completed, it was decided, following the hearing of the Senate Investigating Committee on Wild Life at Wabasha, Minn., to extend this survey to the Upper Mississippi River, particularly to the Upper Mississippi Wild Life and Fish Refuge near Wabasha, Minn., and to Lake Pepin, as the water level in the Wild Life Refuge is to be raised by the dams of the 9-foot channel. The entire survey therefore was extended from Quincy, Ill., to Point Au Sable, Minn., in Lake Pepin. Collections and observations were made at 254 different stations.

LAKE KEOKUK AND THE LAKE KEOKUK DISTRICT

PHYSICAL CHARACTERISTICS OF LAKE KEOKUK

Although popularly called a lake, Lake Keokuk must not be confused biologically with true lakes as found in the various mountainous and glaciated areas of the world. Lake Keokuk is merely a widened portion of a large river—the Mississippi—and as such this so-called lake possesses the physical characteristics of a river, with certain modifications attendant to the slower current and greater depth of the impounded water. Specific observations in Lake Keokuk demonstrate clearly that it must be considered as a river unit and not a lake unit.

Temperature.—During the summer of 1930 there were no sharp differences between surface and bottom temperatures of the water in Lake Keokuk, as are regularly found in true lakes. During the month of July the water temperatures off the end of the sea wall near the north entrance to the fore bay at Keokuk, Iowa, where the soundings ran from 33 to 37 feet, ranged from 75° to 86° F. at the surface and from 73° to 84° F. at the bottom. Simultaneous records of top and bottom temperatures were never more than 3.4° F. apart. Temperature records taken at various other stations in Lake Keokuk showed the top and bottom temperature to be much the same throughout the lake.

Turbidity.—There was considerable variation in the turbidity—that is, the parts per million of solids carried in suspension in the water in different parts of Lake Keokuk—and the turbidity varied from time to time at any particular station. Following heavy windstorms down the lake the turbidity of surface water near the sea wall often rose to a value above that regularly found at the head of the lake.

Depth.—As may be seen on the existing charts of Lake Keokuk, a considerable portion of this body of water is over 27 feet deep. Repeated soundings during the past summer confirmed the previous

soundings, and depths ranging from a few inches to 38.6 feet were recorded.

Both temperature and turbidity data show that the water in Lake Keokuk is subjected to a more less constant agitation and turnover; that is, the "rolling over" of the surface and bottom water in the river during its movement downstream continues in the lake. The waters of Lake Keokuk are also readily disturbed by windstorms.

Since the turbidity of the water in Lake Keokuk results from the material carried in suspension downstream by the river proper, the impounding of water by the Keokuk Dam permits a certain amount of silting-out because the water is both deeper and quieter above the dam than in the river proper. These conditions of silting, however, are not peculiar to Lake Keokuk, for in the studies covering the Mississippi from Quincy, Ill., to Point Au Sable, Minn., in Lake Pepin, this same silting-out of suspended material was found wherever the water was slowed down by any cause and over areas varying from a few square feet to many acres in extent. It is only proper to point out that, although the silting-in of Lake Keokuk provides the set of conditions which, perhaps above all others, most seriously affect the fisheries problems in Lake Keokuk, these silting-in conditions are not the result of any factor peculiar to the artificially constructed lake but that they obtain with equal force wherever any obstruction, either man-made or natural, blocks the movement of the water temporarily or over a period of time.

WATER OF LAKE KEOKUK

As the water in Lake Keokuk is supplied almost entirely by the main stream of the Mississippi, the difference between the water of Lake Keokuk and that of the river proper, either above the level of backwater near Keithsburg, Ill., or below the dam, must be attributed largely to conditions arising from the impounding of this large volume of water in the Lake Keokuk Basin. Sedimentation—that is, the silting-in of the bottom of the lake with a material containing incompletely decomposed organic matter—seems to be the dominant factor producing the changes noted in the water of Lake Keokuk.

Oxygen.—Detailed studies of the oxygen contained in the water of the Mississippi River were made throughout the summer of 1930. From these studies it was found that the average per cent of saturation of the water in Lake Keokuk with oxygen was around 57 per cent for the bottom and 60 per cent for the surface. Taken in midsummer, when the oxygen production of the aquatic plants in the stream was at its maximum, these oxygen values probably represent an optimum of the factors considered. It must be pointed out here that 60 per cent and 57 per cent saturation are ample for the maintenance of ordinary fish life so that in midsummer at least the oxygen contained in Lake Keokuk was sufficient to support a suitable fish fauna.

The comparison, however, of the oxygen saturation in the river both above and below Lake Keokuk, is striking. At Dallas City, Ill., which is still in the area of backwater from the Keokuk Dam but which is several miles above the lake proper, the surface water showed an average oxygen saturation of about 83 per cent and the bottom water at the same place an average saturation of about 80

er cent; that is, the river water at Dallas City, Ill., before reaching the Lake Keokuk Basin was carrying over 20 per cent more oxygen than the same water after being impounded in Lake Keokuk.

These figures are striking in connection with the oxygen demand of the silt bottom on the floor of the Lake Keokuk Basin. It has been pointed out by various engineers that water flowing over dams is largely reaerated, and samples of water taken just below the Keokuk Dam at the Turbine Pool and at the tailrace from the powerhouse showed an oxygen saturation of between 70 and 80 per cent; however, the mere passage of the water over the dam does not remove the organic material contained in the water, and a series of oxygen determinations made at La Grange, Mo., some 30 miles down the river below the dam, showed that the oxygen want from the organic material contained in the water at that point was such that the oxygen saturation had been reduced to an average of about 70 per cent. The La Grange values for oxygen were therefore higher by some 10 per cent than those of the surface water in Lake Keokuk but were some 10 to 15 per cent lower than the oxygen saturation of the water near Dallas City, Ill.

Of course, it must be recognized that there are several factors contributing to the actual amount of dissolved oxygen in the water at La Grange, Mo., besides the organic material spilled over from Lake Keokuk, but the river bottom between Keokuk and La Grange is very largely sand, so that the conditions for purification are favorable in that district, which, in a measure, should offset the sewerage addition from the city of Keokuk. It does, therefore, seem significant that in the face of all of the combined factors the oxygen level of the water at La Grange, Mo., had not risen to the value found in the vicinity of Dallas, Ill., after its trip over the dam and downstream on a sandy bottom for some 30 miles.

pH value and carbon dioxide.—The water in Lake Keokuk was slightly more acid than that of the river both above and below the dam. In the vicinity of the sea wall at Lake Keokuk the surface water, as determined by a large series of readings during the month of July, had an average pH of approximately 7.6, both surface and bottom, while the surface water at Dallas City, Ill., averaged between pH 7.8 and 8 and the bottom water at the same point was approximately 7.8.

The free carbon dioxide in Lake Keokuk was higher than that of the river water above Lake Keokuk. The lowest carbon dioxide values were found in the determinations for the river water in the vicinity of Keithsburg, Ill. It may be noted in this connection that the bacterial counts in the river water at this place were also the lowest found between Quincy, Ill., and Point Au Sable, Minn.

Plankton.—As plankton provides the basic food for young fish, and through the phytoplankton the basic food substances in the water are made available to fishes, plankton studies were made throughout the survey. Three standard procedures were employed, namely, quantitative studies of the total plankton per cubic meter of water, and qualitative studies as determined by tow nets and by trawl nets. The data obtained from the trawls were useful also in supplying information concerning the abundance of small fish as well as macroplankton. Summarizing the information obtained on plankton, the conspicuous observation was that of the paucity of plankton

organisms, both plant and animal in Lake Keokuk, during the summer of 1930.

In a previous plankton survey of this body of water Galtsoff² noted that the volume of available plankton in Lake Keokuk was much lower than the volume of available plankton in the Mississippi River above Rock Island and particularly in Lake Pepin. This relative abundance was confirmed in the present survey, but the actual amount of plankton present in Lake Keokuk in 1930 per unit of water was conspicuously less than that found by Galtsoff in 1921.

Two factors must be considered in interpreting these results. The condition of water in Lake Keokuk may have been such as to prevent the production of a large amount of plankton; that is, the chemical conditions in the lake may have become less favorable for the multiplication of plankton since 1921. On the other hand, it must be borne in mind that plankton is not produced to any large extent in rapidly moving water but the potomoplankton is supplied to the river proper largely from the more quiet backwaters and bayous.

As will be noted in another section of this report, the littoral zone of Lake Keokuk has been practically eliminated by human agencies; consequently there is very little lateral quiet water to contribute plankton to Lake Keokuk. During the summer of 1930 the Mississippi River reached a stage lower than has been known during the past 25 years, and consequently large areas behind wing dams and in chutes were dry during this summer, which under conditions of average water stage would have been submerged and would have contributed plankton to the river.

It was noted throughout the summer that the actual amount of plankton obtained at all stations below Rock Island, Ill., was very much less than the amount obtained at similar stations by Galtsoff in 1921. It is entirely probable, therefore, that the low stage of the river may have been a determining factor in this reduction of the amount of plankton. It may be pointed out, however, in this connection that the amount of available flood land along the Mississippi is being greatly reduced annually, as the various sloughs and chutes, which have been cut off from the main channel by the construction activities of the War Department, are reclaimed each year for agricultural purposes. A progressive decline, therefore, in the actual amount of plankton produced in the Mississippi River between Rock Island, Ill., and Keokuk Dam is to be expected following this annual reduction of the plankton producing areas. No evidence was obtained during the 1930 survey that the water in Lake Keokuk was unfavorable to maintenance of plankton in spite of the fact, which has just been noted, that the actual volume of plankton taken in Lake Keokuk was very small.

For comparison with Lake Keokuk the plankton catches made in the river above Rock Island, Ill.—that is, between Rock Island, Ill., and Point Au Sable in Lake Pepin—may be mentioned. A short distance above Dubuque, Iowa, the floating phytoplankton became abundant enough to be noticeable as a greenish film over the

² Galtsoff, P. S. Limnological observations in upper Mississippi, 1921 (with bibliography). Bulletin, U. S. Bureau of Fisheries, Vol. XXIX, 1923-24. Document No. 958.

water in quieter portions of the stream. Actual plankton samples taken showed a progressive increase in both phytoplankton and zooplankton from McGregor, Iowa, to Reeds Landing, Minn., at the foot of Lake Pepin.

In Lake Pepin itself the plankton hauls were large and the volume of plankton compared favorably with that obtained in this lake in 1921 by Galtsoff. As the wing dams have cut off considerable portions of the backwater in the Mississippi River above Rock Island as well as in the Mississippi River below Rock Island, and as the water stage was excessively low in the Mississippi above Rock Island (it was often barely possible to locate 5 feet of water in the main channel), it seems probable that some other factor in addition to the removal of plankton supply areas was operating in the river below Rock Island to reduce the plankton volume of Lake Keokuk. Galtsoff has pointed out in his work that the volume of plankton below Rock Island was conspicuously less in 1921 than that above Rock Island, and he accounts for this on the basis of destruction of the plankton by the rapids in the vicinity of Rock Island. The actual values of plankton caught in the 1930 survey, however, show greater discrepancies between the plankton volumes below Rock Island and those above Rock Island than were found by Galtsoff in 1921.

Returning to the plankton in Lake Keokuk, plankton studies made in one small stream entering Lake Keokuk on the Illinois side about 3 miles above the dam show that the quiet pond areas of this stream were producing in 1930 a good supply of plankton, and the plankton volume in Lake Keokuk itself within 20 to 30 feet of the mouth of this stream was higher than the plankton volume anywhere else in Lake Keokuk. This demonstrates, of course, the value of these lateral plankton supply areas in contributing plankton of the lake itself.

BOTTOM CONDITIONS IN LAKE KEOKUK

The bottom of Lake Keokuk from Galland Light to the power house at Keokuk, Iowa, a stretch of from 5 to 6 miles, is covered with a soft, very fine, brown silt. The depth of this silt varies, but in the summer of 1930 in some parts of Lake Keokuk this silt deposit was found to be over 6 feet deep, and in many places dredgings and soundings showed it to be more than 3 feet deep. This silt layer on the bottom of Lake Keokuk is the natural result of the sedimentation following the slowing down of the waters of the Mississippi which are so heavily loaded with suspended material.

Gross analysis of the silt taken from various depths (6 inches to 30 feet) showed the silt to be made up of extremely fine erosion material; that is, soil wash brought in by streams. The silt also contained fragments of animal and plant debris, varying in size from microscopic particles to pieces of leaves, stems, and even branches of trees. Fish bodies and other portions of animal debris were also recovered now and then in the course of dredging work.

Chemically this silt consists of a clay base, mixed, however, with a rather high per cent of organic material. This organic material has not been reduced to its simplest form in the chain of bacteriological decomposition, and was, therefore, available for further decom-

position, supporting, as the bacteriological study showed, an abundant bacterial flora. This silt bottom represents an enormous oxygen demand as the chemical tests on oxygen demand of the water very definitely showed. That decomposition was continuing even in the rather deep layers of silt in the bottom of Lake Keokuk was easily demonstrated in the dredging operations, for any disturbance of the bottom even at a depth of 30 feet or more was followed by the ebullition of large numbers of gas bubbles. This gas was a mixture of carbon dioxide, methane, and various sulphur derivatives. In some localities the sulphurous material liberated was abundant enough to give the dredged samples, when hauled onto the deck of the boat, a distinctly sulphurous odor. In some of the shallower portions of the lake the ebullitions of gases from the decomposing silt at the bottom were sufficiently rapid to cause bubbles to rise through the water on quiet days even when the bottom was undisturbed by dredging operations. This ebullition of gas was observed at several stations in Lake Keokuk.

By means of a Peterson dredge measured quantities of the bottom silt were collected, carefully washed through a series of graded screens, and the bottom fauna and flora studied, both qualitatively and quantitatively. In the samples taken from the body of the lake proper—that is, samples taken 30 feet or more from shore—the bottom fauna consisted almost entirely of those forms known to inhabit poorly oxygenated regions. The bottom fauna varied slightly in different parts of the lake, but as collected included in general only sludge worms, bloodworms, corethra, a few snails of the pulmonate group, tiny bivalves of the genus *Musculium*, and several species of leeches. In addition to the forms just mentioned, as the shore of the lake was approached, occasional fresh-water mussels were found and in those localities where the shore vegetation extended out into the water, dragon-fly larvæ and other aquatic insects were added. At a few situations in the lake the larvæ of the large May fly, *Hexagenia*, were taken, although this species was very much more abundant upriver than in the lake proper.

Summarizing the bottom fauna of the lake as a whole as shown by a large number of hauls, dredgings, and samplings during the month of July, 1930, the fauna was found to consist almost entirely of those forms tolerant of low oxygen conditions and, therefore, forms which have come to be regarded as indices of a polluted or biologically unfavorable body of water. The once abundant beds of fresh-water mussels which were worked commercially in the region now covered by Lake Keokuk before the erection of the dam have all disappeared. Dredgings were made at points known to have been included in the once productive mussel beds; but even a heavy iron dredge weighing nearly 100 pounds and capable of lifting 6 cubic feet of bottom failed to bring more than an occasional dead shell from this region, the dredge merely sinking several feet into the bottom silt before closing.

The fauna just described was characteristic of all parts of the lake bottom where there was deposit of silt. On the other hand, from a few stations in the lake, even in deep water, where owing to the peculiarities of the water currents the bottom was kept free from silt, quite a different fauna was found. On cinders, stones, or even water-logged portions of trees, taken from these from areas free from

silt, large numbers of caddis-fly larvæ, Neuroptera larvæ, flatworms, and beetle larvæ were found, together with occasional specimens of crayfish and Gomphids and a few leeches. Several species of algæ were also taken in these hauls. While this fauna does not speak for ideal conditions at the bottom of the lake, even in those portions free from silt deposits, it does show that a fauna supplying a considerable amount of fish food was maintaining itself in the silt-free areas.

SHORE ZONE OF LAKE KEOKUK

The shore zone in Lake Keokuk is very narrow; that is, the silt deposits come up practically to the water's edge in most parts of the lake. Only a narrow zone, in many places less than a yard wide, is kept free from the silt deposit by the wave action along the shore. Shore conditions in Lake Keokuk are, therefore, very unfavorable for the spawning of fish and for the development of fry and fingerlings. This narrow shore zone is the result of several factors. Around the entire lake almost at the water's edge are automobile roads, and along the Iowa shore railroad tracks come quite close to the water in many places. The construction necessary for the maintenance of these roads or railroads, and the building of summer homes along both shores, have resulted in the elimination of practically all the swampy, marshy, and weedy areas which would constitute the littoral zone, in which fishes could spawn and young fish develop, as usually found along the margins of natural lakes. Along a large portion of the shore line of Lake Keokuk one finds stone riprap placed there either in the course of road construction or by the War Department in connection with its channel-maintenance problems. Nearly all of the few small streams running into Lake Keokuk have been so thoroughly cleared of aquatic vegetation for the sake of pleasure boating, or have been so completely banked in to meet the needs of road construction, that they do not offer fish-spawning grounds or breeding grounds of any consequence.

As a result of the combined action of the silt deposits which encroach from the lake side and the building in of the shore zone by man—an encroachment from the land side—Lake Keokuk proper has been reduced to a huge basin of water with almost no collateral shallow water in which game and food fishes can breed.

UPPER LAKE KEOKUK DISTRICT

The stretch of river above Nauvoo, Ill., extending to Keithsburg, Ill., although not so deep or wide as Lake Keokuk proper may be considered an integral part of the Lake Keokuk district in that the change in water level produced by the dam is noticeable as far up the river as Oquawka, Ill. When this region was first flooded following the construction of the Keokuk Dam, extensive new areas of shallow waters were made available for plankton production, fish-spawning grounds, and refuges for young fishes. At various times during the last few years considerable portions of these lateral areas have been reclaimed for agricultural purposes by the construction of levees, dikes, and pumping stations. The reclamation of these areas of shallow water reduced the production of game fish in those regions where the reclamation was accomplished. A striking case in point is

that of the region on the Iowa side opposite Dallas City, Ill. After the construction of the Keokuk Dam, bass, crappie, and other game fish increased in the vicinity of Dallas City, and sport fishing was generally recognized as much better than before the dam was built. When these shallow areas which were providing the breeding grounds for these various species of game fish were reclaimed sport fishing in the vicinity of Dallas City, Ill., dropped abruptly, and in the summer of 1930 little evidence was found of game fish in this portion of the Lake Keokuk district.

In the upper Lake Keokuk district another type of habitat resulting from the new conditions produced by the building of the dam is evident, namely, the flooded forest district. Considerable areas of almost submerged forest trees are to be found in the vicinity of Dallas City, Ill. These forest trees were, of course, speedily killed by the rising water, and portions of their dead trunks can now be seen projecting above the water on either side of the steamboat channel. Previous students of this district found an increase in plankton immediately following the submerging of these forested areas, but this seems to have been a transitory increase, for in the summer of 1930 this region of submerged trees contained no more plankton than the river proper. In the shallower portions of this area of submerged forest trees the silting in is progressing very rapidly, so that there are large fields of relatively shallow water; that is, water 3 to 6 feet deep supporting growths of various species of pondweeds. Study of the fauna in these pondweed districts adjoining the submerged wooded areas showed a considerable insect fauna supporting itself on the vegetation proper, and from the bottom in these areas large numbers of May-fly larvæ were collected. The conditions for the production of fish food seem fairly good in these weedy areas except for one or two conditions. First, the diking in of the shallow lateral areas of the river has produced a much stronger current through these areas of submerged trees than would be found in the littoral zone proper, therefore only those animals which are able to cling to vegetation or maintain themselves in a current are able to live in these particular weedy areas. The movement of water through these areas was so fast that relatively few small fish were sheltered by these weeds. The second factor is that of silt. When the water becomes shallow enough for these aquatic plants to gain a foothold the silting-in proceeds so rapidly that the bottom fauna consists only of those forms capable of surviving in the layer of silt which forms around the roots of the plants in spite of the current. To summarize the fields of aquatic vegetation which are coming into the submerged forest areas near Dallas City differ from the littoral pond type in that the water is moving through them with considerable current and the silting in is proceeding very irregularly, rapidly in some parts and not at all in others. As a result these fields of vegetation were not contributing any large amount of plankton to the river nor were they supporting any large fauna of young fishes in the summer of 1930.

Oxygen, carbon dioxide, relative acidity, oxygen want, and bacterial conditions were all more favorable to fish life in the upper Lake Keokuk district than in the lake basin proper for reasons which have been discussed in a foregoing section.

FISHES OF THE LAKE KEOKUK DISTRICT

The fish fauna of the Lake Keokuk district was studied intensively some years ago by Coker,³ so that fortunately data were available for comparison with conditions found in 1930. In Lake Keokuk proper there was very little sport fishing the summer of 1930. From the sea wall and from certain other vantage points about the lake quite a few large catfish, an occasional sheepshead and a considerable number of large carp were caught by pole-and-line fishermen. Commercial fishing in the lake was yielding a "fair" to "poor" catch, judging from the comments of various commercial fishermen questioned. This catch consisted for the most part of large catfish, large carp, and a few sheepshead. Above Kauvoo, Ill., commercial fishing was described by the fishermen themselves as "fair," and at several points on the river, particularly at Dallas City, Ill., the writer saw medium to large carp being packed in ice for shipment to New York in carload lots. Various commercial fishermen were visited during the summer and the Lake Keokuk district was found to be producing relatively large quantities of carp, and fair quantities of sheepshead, catfish, and various other "rough" fish. In summary the Lake Keokuk district is supporting a considerable number of commercial fishermen and a modest commercial fishery.

Seining operations in the littoral zone and in various places in which young fish might be expected in Lake Keokuk proper yielded very small catches. As has been discussed at a previous section, the littoral zone is almost obliterated in Lake Keokuk proper and, consequently, there was no shallow-water habitat in which young fish could find refuge. Seine hauls made along shore yielded only minnows, young sheepshead, young carp, a few young catfish and occasionally stray individuals of other species. No young bass, young sunfish, or other young game fish were found in these studies. Besides, the total number of young fish caught was small. The replacement fauna—that is, the young fish in Lake Keokuk proper—consisted very largely of sheepshead, carp, and catfish. Seining operations in the mouths of the small streams tributary to Lake Keokuk proper yielded very small catches, for, as has been pointed out, these streams are so modified by human activities that their shallow parts afford little shelter for young fish. In one small stream, however, emptying into Lake Keokuk from the Illinois side, many young bass, crappie, bluegills, and other game fish were found. This stream is an exception demonstrating the conditions required for young fish, however, as this stream rises in a series of waterlily and sagittaria ponds and is filled with undisturbed aquatic vegetation. In this stream the largest plankton catches in the Keokuk district were made, and local fishermen state that good bass, sunfish, and other game fish were caught in Lake Keokuk near the mouth of this stream. The reason is of course obvious.

Moving up river from the main Lake Keokuk Basin into the upper Lake Keokuk district the same conditions obtained as in Lake Keokuk proper, namely, wherever proper breeding grounds and refuges

³ Coker, R. E., Keokuk Dam and the Fisheries of the Upper Mississippi River. Bulletin, U. S. Bureau of Fisheries, Vol. XLV, 1929. Fisheries Document No. 1063.

for young fish are maintained undisturbed the game fishing was good. In the river proper, particularly in those portions where the lateral shore zone shallow water had all been reclaimed for agricultural purposes, sport fishing was almost negligible. Carp, catfish, buffalo, and sheepshead were relatively abundant judging from the catches which were seen in the local commercial fish houses. There can be no question but that the entire Lake Keokuk district is producing large quantities of German carp.

MUSSELS IN THE LAKE KEOKUK DISTRICT

The fresh-water mussels present another economic fisheries problem which must be considered in connection with the problems of changes in water level. Before the building of the Keokuk Dam and before the restriction of the channel by wing dams, the Mississippi River between Keithsburg, Ill., and Keokuk, Iowa, produced large quantities of commercial shells. Perhaps the greatest single factor in the reduction of mussel fauna in the Mississippi River has been the intense shelling to which these beds have been subjected, so that a decline in the unprotected mussel beds was inevitably to be expected. However, changes incident to navigation needs, pollution by municipal and industrial wastes, and the depletion of the host fish on which these various species of mussels pass a portion of their development have all been contributing factors in hastening the decline of the mussel population of the Mississippi River. Specifically in the Lake Keokuk district the mussels have been practically wiped out from the Keokuk Dam to Edwards River near New Boston, Ill. In the Lake Keokuk Basin only one species of commercial mussel, namely, the mapleleaf was taken in deep water—that is, in water more than 30 feet offshore—and this species was found only in very restricted areas and represented by a very limited number of individuals. The once fine beds of niggerheads and other commercial mussels existing in the Mississippi River near what were then the old Keokuk rapids have been entirely covered by the silt layer which has been deposited in the bottom of the lake. Alongshore two or three species of paper-shells which are worthless commercially are thriving in Lake Keokuk. These shells have certain bearing on fisheries problems in that the mussels of these species contribute slightly to the purification of the water and, being thin-shelled species, are readily eaten by certain species of fish.

Above Nauvoo, Ill., scattered beds of mussels were found in isolated and protected places where for one reason or another the shells had not been covered by the silting in and were inaccessible to commercial shellers. Even in these small isolated colonies the mussel fauna was reduced to those species more tolerant of muddy water and less favorable conditions, and the yellow sand shell was entirely wanting. Near Edwards River between Keithsburg and New Boston a bed of mussels sufficiently large to support commercial activities was found. Here the conditions were such that the mussels were not covered over with silt and were protected from the shifting sand which has covered so many mussel beds in this part of the river.

To summarize, dams and backwater in promoting the deposition of silt produce conditions speedily fatal to mussels wherever silting-in is possible. This was well demonstrated on a particular bed near

quawka, Ill., where a recent change in the position of the current, sulting from the construction of certain wing dams, had brought out the rapid silting in of the bottom over a once fairly productive mussel bed. Only a few species of mussels and relatively few individuals of these were able to maintain themselves against this abrupt change in environment, and as a result large quantities of dead shells which would have been of commercial value had they remained alive were found. Consequently the silting-in problem is not one of the large dam as far as mussels population is concerned. Wing dams were equally effective in the destruction of the mussel fauna wherever they created quiet water in which silting-in could take place. These newly silted-in areas back of wing dams were, however, supporting a rather abundant population of paper shells worthless, of course, from the standpoint of button industry but of some value as fish food for certain species of fishes. Deep water over a silt bottom with its attendant reduction in oxygen presents a habitat which is, of course, fatal to mussel life wherever found.

CONDITIONS IN UPPER MISSISSIPPI

The second half of the 1930 survey was conducted in the river above Rock Island, Ill., intensive studies being made in the Upper Mississippi River Wild Life and Fish Refuge near Wabasha, Minn., and in Lake Pepin. This portion of the survey was intended to supply data for comparisons with those obtained in the Lake Keokuk district, and also if possible, to suggest what changes might be expected in the Wild Life and Fish Refuge following the rise of water level which will occur when the dams for the 9-foot channel are built. As a considerable portion of data from this part of the survey has already been discussed in connection with Lake Keokuk district a rather brief summary will suffice here.

WILD LIFE REFUGE NEAR WABASHA, MINN.

The striking difference between the upper Mississippi district and the Lake Keokuk district is the amount of undisturbed shallow water alongshore and in the backwaters zone. Considerable portions of the sloughs and chutes which have been cut off, partially or completely, by the War Department construction remain still unreclaimed and are therefore productive of large amounts of plankton and young fish. As a result the plankton content of the river increased progressively from Rock Island, Ill., to Lake Pepin. Seining operations along the shore and in these backwaters and sloughs yielded large numbers of young smallmouth and largemouth black bass as well as crappies and sunfish, and the replacement fauna near Wabasha included therefore a large proportion of valuable game fishes. In the channel, carp, red horse, and catfish were abundant.

Oxygen want, carbon dioxide, carbonates, and the other physico-chemical characteristics of the environment were more favorable to good mixed-fish fauna in the Wabasha district than in the Lake Keokuk district.

However, the erosion and the silting-in problems were essentially the same in Wabasha district as in the Keokuk district, except that

in the immediate vicinity of Wabasha the erosion deposit consists largely of clean sand. Wherever wing dams, closing dams, and other obstructions had been placed in the river the silting-in was proceeding at a rapid rate. A striking example of this can be seen at the Beef Slough near Alma, Wis. This slough, which once carried the main channel of the river and down which enormous rafts of logs were moved during the memory of now-living steamboat captains, has been cut off by the wing dams and closing dams and has silted in to such an extent that a considerable portion of this slough is above low-water level, having filled in with soil solid enough to support the weight of a man. As there are still ample unreclaimed backwater ponds and sloughs in the Wild Life district to support large numbers of young fish and to supply a large plankton fauna, and as there are no deep bodies of impounded water in this region, the detrimental effects of the silting-in with erosion material are not so evident at present in Wabasha district.

A study of the mussel fauna of this district, however, shows that the same conditions hold as in the Lake Keokuk district. Large beds of mussels have been covered by the silt and sand deposits which have settled out behind wing dams and at other places along the river where the improvements incident to navigation needs have produced areas of relatively quiet water. In these areas of quiet water paper shells are increasing. A specific case may be used to demonstrate the point. At Alma, Wis., there is still a moderately large bed of commercial mussels near the base of a stony cliff. The talus from this cliff has provided a rocky bottom on which the mussels can maintain themselves in spite of a rather swift current, and the position of the channel improvements is such that a strong current is maintained just at the edge of this bed. The combined action of current which prevents silting in on this bed and of the rock slide which has maintained a rocky bottom have provided conditions favorable for this bed of commercial mussels.

LAKE PEPIN

Conditions in Lake Pepin have been studied from time to time with reference to the fish and mussels population of that body of water. Additional surveys were made during the summer of 1930 for the specific purpose of comparing conditions in Lake Pepin with those in Lake Keokuk. Lake Pepin is a body of impounded river water held by a sand dam which the Chippewa River has thrown across the main channel near Reeds Landing, Minn., while Lake Keokuk is an impounded body of river water held by a concrete dam. The physical conditions resulting, however, from the impounding of these masses of water are very much the same. The fauna at the bottom of Lake Pepin taken in water 20 to 40 feet deep was essentially the same as that taken from the bottom of Lake Keokuk and consisted primarily of sludge worms, bloodworms, pulmonate snails, leeches, and other animals capable of maintaining themselves in environments of reduced oxygen more or less fouled by pollution. The bottom of Lake Pepin is being silted in with essentially the same sort of material as that found in the bottom of Lake Keokuk; and consequently the oxygen, carbon dioxide, and physicochemical conditions of the aquatic environment in Lake Pepin are much the

ame as those in Lake Keokuk. Lake Pepin, however, does have much more available shallow shore water than Lake Keokuk; that is, there are regions in Lake Pepin where an unmodified littoral zone exists. Near the southern end of Lake Pepin opposite Lake Pepin footlight No. 950 a large area has silted in to such an extent that it now supports a large amount of aquatic vegetation as pondweeds and the like and the water depth has been reduced to 10 feet or less. This silted-in area is increasing rapidly and at present provides an excellent shore zone for various species of fish. Bass, sunfish, perch, and other game fish were taken in this area during 1930, and there were many evidences that pole-and-line fishing was good in this district.

The progressive silting-in, however, of Lake Pepin has helped to reduce the mussel production of this lake from several thousand tons annually to only a few hundred tons annually, and the evidence obtained in 1930 showed that still further reduction in the mussel production of this lake may be expected as the silting in continues.

SUMMARY AND RECOMMENDATIONS

(1) The Keokuk Dam, just as any other permanent obstruction of a moving stream, has produced certain physical and chemical changes in the river in the Lake Keokuk district. Those changes having particular bearing on the fisheries problems are:

(a) Large lateral areas were flooded producing extensive tracts of shallow backwaters. These shallow backwaters, as has been demonstrated by observation in the Lake Keokuk district and elsewhere, supplied large quantities of plankton and other fish food, provided spawning grounds, and were available as refuges for young fish. Consequently, while these areas were in existence and were properly maintained, game fish of several species increased in Lake Keokuk district. These lateral areas of shallow water were, however, reclaimed from time to time for agricultural purposes and as a result the breeding grounds and refuges for young fish were greatly reduced. At the present time—that is, the 1930 survey—Lake Keokuk proper as the result of the reclamation of these lateral areas and of shore construction is practically without a littoral zone in which game fish can spawn and in which young fish may develop.

(b) The current of the river has been materially slowed following the impounding of a large volume of water behind the Keokuk Dam. This slowing of the current has made possible a rapid and extensive silting-in of the Lake Keokuk Basin which has resulted in completely changing the bottom fauna of the former river bed. As this silt consists of erosion material mixed with incompletely decomposed organic waste, the bottom fauna in Lake Keokuk has been reduced to those forms capable of withstanding low oxygen and tolerant of the various conditions attendant upon the decomposition of organic waste. This silting in has, therefore, limited fish fauna of Lake Keokuk largely to those species capable of utilizing for food those organisms living in such a silt environment. Consequently, carp, buffalo, and catfish were the dominant fish found in Lake Keokuk. This silting in also has eliminated almost completely the commercial mussel population of the Lake Keokuk district. This silting-in with a mixture of erosion silt and organic waste becomes

a serious factor since such a mixture has a high oxygen demand. In the 1930 survey distinct differences were found in the dissolved oxygen content of Lake Keokuk and the river both above and below the dam in midsummer, and it has been shown by observations on other bodies of water, notably Lake Pepin, that the dissolved oxygen in water above such a silted-in bottom decreases to a point critical for the maintenance of life during the winter months when the surface of the body of water is frozen over.

(c) The depth of the water has been increased to over 15 feet for 4 or 5 miles above the dam. This volume of deep water produces a more acute oxygen demand and mechanically restricts the purification of the silt which has settled to the bottom.

(2) Wing dams both in the Lake Keokuk district and elsewhere along the river have produced the same general set of conditions as regards the silting-in of the bottom, except that the wing dams occupy relatively shallow water. The silting-in back of wing dams presents, however, a less acute situation to those animals capable of moving about as other portions of the river near by are available and the decomposition products are swept away more readily from behind wing dams by the adjoining river currents. The mussel population has suffered particularly, however, from the construction of wing dams because these animals do not move rapidly and are more or less restricted to particular habitats.

(3) Large numbers of game fish, both young and old, were found in the river in the Wabasha district. This district has ample lateral backwaters producing quantities of plankton and supplying refuges for young fish. Consequently, the detrimental effects of silting-in were not so noticeable in the Wabasha district as in the Lake Keokuk districts. Studies on the mussel population, however, showed that silting-in is a serious factor even in the Wabasha district.

(4) The conditions in Lake Pepin, a natural body of impounded river water, were very similar to those in Lake Keokuk as regards silting-in character of bottom, oxygen, and the physicochemical factors of the environment. In Lake Pepin, however, areas of shallow water containing weeds, producing large quantities of plankton, and supplying suitable spawning grounds and refuges for young fish are to be found, resulting in a more abundant fish fauna, in general richer in game fish in Lake Pepin, than in Lake Keokuk.

(5) Summarizing all of the available data from the survey it is evident that from the standpoint of fisheries problems the fixed-level dams have many advantages over arrangement allowing sudden changes in the water level of the river. As has been demonstrated in the Lake Keokuk district a fixed-level dam will flood sufficient lateral land to provide desirable shallow water areas producing quantities of fish food maintaining large numbers of young fishes. If the water level be suddenly changed these shallow areas will suffer first. Both the forms producing fish food and large numbers of young fishes will be destroyed if the change in water level be made during the summer, losses which can not be replaced during that season. It is recommended, therefore, that in the vicinity of the fixed-level dams suitable portions of these lateral flooded areas be maintained as fish refuges. This procedure will avoid

the complications arising from the withdrawal of these areas for other purposes, as has happened in the vicinity of Dallas City, Ill., to the detriment of the fisheries interests. It is recognized, however, that question may be raised at once as to the relative value of these areas for agricultural purposes as against their value for fisheries purposes.

(6) The outstanding factor producing changes in the Mississippi River fauna seems to be that of erosion silt. It must be borne in mind, of course, that with the increasing accessibility of the various parts of the river fishing has increased tremendously and also that, with the increasing value placed on the mussel shells, shelling has been greatly stimulated. As a result many more fish and many more shells have been taken from the river during the past few years than formerly, but aside from the factor of overfishing and over-shelling, erosion silt becomes a serious matter in the river. Soil experts of the Department of Agriculture have shown recently that the silt now carried by the Mississippi River greatly exceeds in volume that which was carried by this same river only a few years ago, and that the annual increment of increase in erosion is rising rapidly. The Mississippi River is, therefore, so loaded with erosion silt that any obstruction of the current slowing down the movement of the water temporarily will produce a rapid silting-in behind the obstruction. This was conspicuous at all points between Quincy, Ill., and Point Au Sable in Lake Pepin. The silting-in overwhelms the bottom fauna faster than it is able to adjust itself, with a result that many species are being eliminated or greatly reduced in numbers. As a complicating factor the erosion-silt suspension, which is almost colloidal in nature, carries down with it when settling out partly decomposed organic waste which has reached the river through municipal sewage and other sources. The nitrogen values of silt taken from the bottoms of Lake Pepin and Lake Keokuk were surprisingly high, and the decomposition of the organic material after it is carried to the bottom by the erosion silt produces gases and other substances which modify the character of the water and reduce the quantity of dissolved oxygen to the detriment of the bottom animals, as has been noted under the discussion of Lake Keokuk. As the result the silting-in behind wing dams and other permanent obstructions in the river below large cities presents a serious complication of the pollution problem.

(7) Bacteriological and chemical studies of the water of the Mississippi River, both in the vicinity of cities and towns and in the portions of the river less closely bounded by civilization, showed that the pollution of the river by municipal sewage and industrial waste has been accomplished to an alarming extent; this factor of pollution in itself, regardless of other conditions in the river, is rapidly reducing the river fauna to such forms as carp and paper shells, which are tolerant of these conditions. The municipal-sewage problem is greatly complicated by presence of soil-erosion material, since the sewage when incorporated with the erosion silt decomposes more slowly than when moving in clear water and consequently the effects of pollution from municipal sewage are being projected farther and farther downstream from the source of pollution.

(8) In conclusion, the findings of the 1930 survey seem to warrant the statement that the construction of permanent dams maintaining a fixed water level in connection with the requirements of navigation need not be incompatible with fisheries interests. On the contrary, the construction of such dams may be made to increase fish production and to better fisheries conditions in the upper Mississippi River if proper cooperation be given by those interested in fish conservation. This involves the setting aside of suitable fish refuges, elimination of unnecessary erosion silt from the Mississippi River, and the removal of various municipal wastes from the stream. These are problems facing the fisheries interests, regardless of the construction work of the War Department.